Precursors of Type C inclusions: Evidences from the New Kind of Anorthite-Spinel-rich Inclusions in the Ningqiang Carbonaceous Chondrite

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Introduction

Type C (plagioclase-Ca-pyroxene-rich) is one of common Ca-Al-rich inclusions in CV3 chondrites, and likely crystallized from melts[1]. Wark[1] proposed that the melts directively condensed from the gaseous nebula under high-pressure conditions ($p^{total} \sim 1$ atm) or with high dust/gas ratios. Beckett and Grossman[2] suggested that Type C could be related with Type A (melilite-rich) inclusions through alteration of melilite and partly spinel in the solar nebula based on the bulk compositions of both types. However, such unmelted alteration assemblages were not reported. In the Ningqiang meteorite, an anomalous carbonaceous chondrite[3, 4, 5, 6], we reported a new kind of anorthite-spinel-rich inclusions referred as to ASI[7], and a Type C inclusion[8]. One of the ASIs is a *fluffy* assemblage of numerous small concentric grains consisting of spinel, anorthite and Ca-pyroxene. It also contains many large spinel-nodules rimmed by melilite and/or anorthite and Ca-pyroxene in the center, and is covered by a melilite-spinel-crust. The other ASIs are the same of the *fluffy* one except for a compact texture with well defined spinel-nodule core. Petrography and mineralogy suggest that the ASIs were not molten. The Type C inclusion consists mainly of anorthite, fassaite and spinel with minor feldspathoids, hedenbergite and melilite, and shows sub-ophitic texture. The petrographical and mineralogical description of ASI was reported by[7]. Here, we show close genetic relationships between Type A, ASI and Type C inclusions.

Evidences for ASI as precursors of Type C inclusions

Compact ASIs consist of 44-47 vol% spinel, 31-33 vol% anorthite, 12-16 vol% Ca-pyroxene and 6-8 vol% melilite with minor sodalite, nepheline, hedenbergite and perovskite. Modal composition of *fluffy* ASI is 22 vol% spinel, 31 vol% anorthite, 29 vol% Ca-pyroxene, 9.4 vol% melilite, 7 vol% feldspathoids, 2 vol% hedenbergite and 0.6 vol% perovskite. The Type C inclusion contains less spinel (17 vol%), but more anorthite (40 vol%) and Ca-pyroxene (42 vol%) with minor melilite and feldspathoids. Except for the high spinel-content of *compact* ASIs, the modal compositions of ASIs are similar to that of Type C in CV3 chondrites[1]. The Ningqiang Type C inclusion has a lower ratio of anorthite/Ca-pyroxene (<1) in comparison with that of CV3 chondrites.

We also measured bulk compositions of ASIs and the Type C inclusion using the broad-beam of electron microprobe. *Compact* ASIs contain 22.9-24.4% SiO_2, 44.5-46.5% Al_2O_3, 13.1-13.5% MgO, 14.1-15.2% CaO, 1.0-1.1% TiO_2, 0.1-0.2% Cr_2O_3, 0.9-1.2% FeO, and 0.2-0.6% Na_2O. *Fluffy* one contains higher SiO_2 (30.9%), CaO (17.8%), FeO (2.8%) and Na_2O (1.4%), lower Al_2O_3 (35.1%) and MgO (10.1%), and similar TiO_2 (1.5%) and Cr_2O_3 (0.1%). The differences, especially for FeO and Na_2O, between *compact* and *fluffy* ASIs are mainly due to more abundant low-temperature alteration products of the latter. The Type C inclusion contains 37.8% SiO_2, 27.5% Al_2O_3, 9.4% MgO, 19.7% CaO, 1.3% TiO_2, 1.2% Cr_2O_3, 2.1% FeO and 1.4% NaO_2. Figure 1 shows the bulk compositions, demonstrating the similarity between ASI and Type C inclusions.

Wark[1] indicated that Type C inclusions have not been significantly evaporated because their bulk compositions were critically different from the evaporation experiment residues, and some Type C inclusions displayed mass-dependent fractionation favoring the light isotopes of Mg. However, condensation of the liquids of Type C inclusions in the solar nebula[1] seems unlikely based on the recent condensation calculation of CaO-Al_2O_3-MgO-SiO_2 liquid[9]. Since the bulk and modal compositions of ASIs are the same as Type C inclusions, we propose that Type C inclusions crystallized from liquids by melting ASIs which

formed through alteration of Type A inclusions as discussed below.

Evidences for a genetic relationship between ASI and Type A inclusions

The loose texture of *fluffy* ASI suggests that it has not been melted, while the sinuous texture of *compact* ones formed probably by sintering the fine-grained assemblages during a mild heating episode. The mineral sequence of the small grains in order of spinel, anorthite and Ca-pyroxene towards voids in *fluffy* ASI is inconsistent with condensation sequence which predicted Ca-pyroxene before anorthite[9]. On the other hand, melilite in the spinel-nodules and melilite-spinel-crust shows a texture of replaced by anorthite. Based on the observed mineral coexistence, the alteration reactions are proposed as below:

$$2Ca_2Al_2SiO_7\ (Geh) + MgAl_2O_4\ (Sp) + 6SiO_2\ (g) = 3CaAl_2Si_2O_8\ (An) + CaMgSi_2O_6\ (Di)$$

$$2Ca_2MgSi_2O_7\ (Ak) + MgAl_2O_4\ (Sp) + 4SiO_2\ (g) = CaAl_2Si_2O_8\ (An) + 3CaMgSi_2O_6\ (Di)$$

Given all anorthite was formed by the above reactions and the melilite has an average composition of Geh_{86} in ASIs, primordial compositions of the ASIs before the reactions can be calculated, which are plotted in Type A range in Figure 1. Modal compositions of the precursors of ASIs can also be calculated to be 61-64 vol% spinel, 33-34 vol% melilite and 2-8 vol% Ca-pyroxene for those of *compact* ASIs, and 36 vol% spinel, 41 vol% melilite and 23 vol% Ca-pyroxene for that of *fluffy* one. The precursors of ASIs show high content of spinel, but the melilite/Ca-pyroxene ratios (*compact* ASI >5.3, *fluffy* one ~1.8) is within or close to the range of Type A and distinguished from that of Type B and C[1]. Hence, we proposed that ASIs formed by high-temperature alteration of spinel-rich Type A inclusions in the solar nebula.

Conclusions

Some Type A inclusions, especially the spinel-rich ones, probably experienced high-temperature alteration and formed the anorthite-spinel-rich inclusions (ASIs). Later, some ASIs were melted in the solar nebula and crystallized into Type C inclusions.

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References [1]Wark, D. A. (1987) **GCA 51**, *221-242*; [2]Beckett, J. R. and Grossman, L. (1988) **EPSL 89**, *1-14*; [3]Rubin, A. E., et al. (1988) **Meteoritics 23**, *13-23*; [4]Kallemeyn, G. W., et al. (1991) **GCA 55**, *881-892*; [5]Kallemeyn, G. W. (1996) **LPSC XXVII**, *635-636*; [6]Kimura, M., et al. (1996) **Proc. Ind. Acad.** *(in press)*; [7]Lin, Y. and Kimura, M. (1996) **LPSC XXVII**, *755-756*; [8]Lin, Y., et al. (1996) **Antarctic Meteorites XXI**, *87-89*; [9]Yoneda, S. and Grossman, L. (1995) **GCA 59**, *3413-3444*;

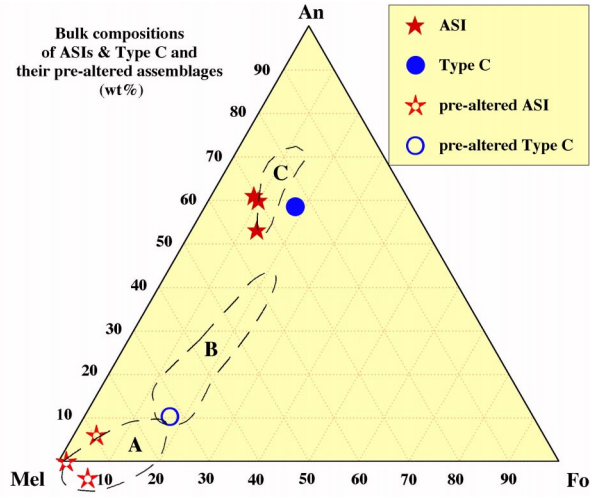

Fig. 1 Bulk compositions of ASIs and their pre-altered assemblages are plotted in the ranges of Type C and Type A inclusions in CV3 chondrites, respectively. A Ningqiang Type C inclusion and its pre-altered assemblage are also shown for comparison.